

Laser Sounder for Measurement of CO₂ Concentrations in the Troposphere for the ASCENDS Mission - Progress

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Abstract: We report progress in assessing the feasibility of a new satellite-based laser-sounding instrument to measure CO₂ and other trace gas abundances in the lower troposphere from space.

1. INTRODUCTION

CO₂ measurements from ice cores show that atmospheric CO₂ concentrations are now higher than in the past 400,000 years. It is becoming increasingly important to understand the nature and processes of the CO₂ sinks, on a global scale, in order to make predictions of the future atmospheric composition. Accurate measurements of tropospheric CO₂ abundance with global-coverage, ~200 km spatial and monthly temporal resolution are needed to quantify processes that regulate CO₂ storage by the land and oceans [1].

The NASA Orbiting Carbon Observatory (OCO) is the first space mission focused on measuring atmospheric column abundances of CO₂ and O₂. It will measure several spectral absorption bands for these gases when viewing selected Earth scenes which are illuminated by sunlight. The OCO mission will yield important new information about global atmospheric CO₂ distributions. However there are some unavoidable limitations imposed by its measurement approach. These include best accuracies only during daytime at moderate to high sun angles, interference by clouds and optical scattering by thin clouds and aerosols, and limited response from CO₂ variability in the lower tropospheric CO₂ column. The 2007 NRC Decadal Survey for Earth Science [2] has recommended addressing these un-met measurement needs in follow-in laser-based CO₂ measuring mission called ASCENDS.

We have been in developing a laser technique for the remote measurement of the tropospheric CO₂ concentrations from orbit [3-6]. Our initial goal is to demonstrate a lidar technique and instrument technology that will permit measurements of the CO₂ column abundance in the lower troposphere from aircraft at the few ppm level. Our final goal is to develop a space instrument and mission approach for active CO₂ measurements. This will allow continuous highly accurate measurements of CO₂ mixing ratio from orbit, over land and

ocean surfaces, made in the presence of typical atmospheric scattering conditions.

2. APPROACH

Previous and some ongoing efforts to develop laser instruments for measuring atmospheric CO₂ have used the 4.88 μ m [7] and 2 μ m [8-11] bands. Our approach is to use the 1570nm band and a dual channel laser absorption spectrometer (ie DIAL lidar used an altimeter mode), which continuously measures at nadir from a near polar circular orbit (Figure 1).

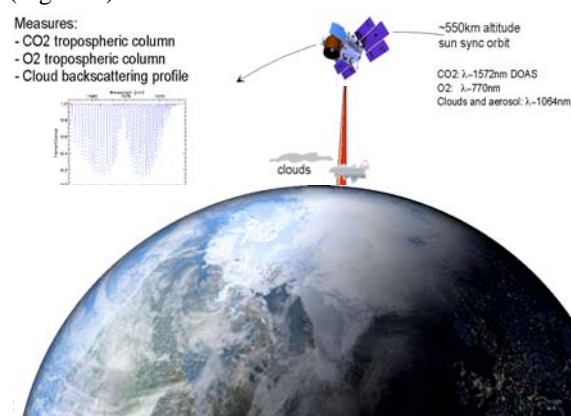


Figure 1- Measurement concept for the space-based CO₂ Laser Sounder.

We use several tunable fiber laser transmitters allowing simultaneous measurement of the absorption from a CO₂ absorption line in the 1570 nm band [12], O₂ extinction in the Oxygen A-band, and surface height and aerosol backscatter in the same measurement path. The approach directs pulsed co-aligned laser beams from the instrument's lasers toward nadir, and measures the energy of the laser echoes reflected from land and water surfaces. During the measurement the laser wavelengths are stepped across a selected CO₂ line near 1572 nm and a pair of O₂ lines near 765 nm at kHz rates.

The lasers are a MOPA architecture using tunable diode seed lasers and fiber amplifiers, and have spectral widths much narrower than the gas absorption lines. The receiver uses a ~1.5-m diameter telescope and photon counting detectors [13], and measures the background light and energies of the laser echoes from the surface along with scattering from any clouds and aerosols in the path. The gas extinction and column densities for the CO₂ and O₂ gases are estimated from the ratio of the on- and off-line signals via the differential optical absorption technique.

Pulsed laser signals and time gating are used to isolate the laser echo signals from the surface, and to exclude photons scattered from any clouds and/or atmospheric aerosols in the path. The time gated detection approach also minimizes the noise from solar background in the daytime. Using pulsed laser wavelength measurements which are sequenced in time also eliminates the shot noise from the other signal wavelengths and hence maximizes the measurement sensitivity.

Lines in the 1570 nm CO₂ band [13] shown in Figure 2 are well suited for this measurement. The band is largely free from interference from other species, has absorption lines with the needed temperature insensitivity and strengths [14], and is within the spectral range of high power fiber lasers and sensitive photon counting detectors.

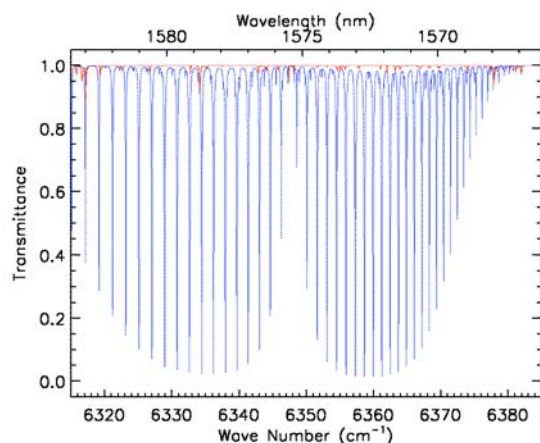


Figure 2 – 2-way atmospheric absorption from space for the 1570 nm CO₂ band (from HITRAN). The laser sounder uses measurements of a single absorption line near 6360 cm⁻¹.

Our technique uses the on-line wavelengths tuned to the sides of the gas absorption line. This exploits the atmospheric pressure broadening of the gas lines to weight the measurement sensitivity to the atmospheric column below 5 km. This maximizes sensitivity to CO₂ changes in the boundary layer where variations caused by surface sources and sinks are largest. Simultaneous measurements of total pressure use a pair of lines in the Oxygen A-band near 765

nm. Laser altimetry and atmospheric backscatter profiles are also measured simultaneously, which permits determining the surface height and hence path length, as well as measurements made to cloud tops and through aerosol layers.

The laser sounder approach has some fundamental advantages over measurements with passive sensors using reflected sunlight. It measures gas absorption in a common nadir/zenith path and the narrow laser divergence produces small laser footprints. The laser sources allow measurements in sunlight and darkness allowing global coverage. It can measure continuously over the ocean, to cloud tops and through broken clouds. The lasers are pulsed and potential measurement errors from scattering from clouds and aerosols are greatly reduced by using time gating in the receiver. Nonetheless, the optical absorption change due to a few ppm change in CO₂ is quite small, <1%, which makes achieving measurement sensitivity and stabilities challenging. Signal-to-noise ratios and measurement stabilities of > 700:1 are needed to allow CO₂ mixing ratio estimates at the few ppm level.

3. MEASUREMENT DEMONSTRATIONS

We have calculated several characteristics of the technique, and have demonstrated key aspects of the laser, detector and receiver approaches in the laboratory. We have also measured O₂ over a 206 m long path and CO₂ over 206m, 400m, 1.3 and 2.2 km long open horizontal paths [6] using a breadboard version of the sensor. Figure 3 shows an example of a wavelength scan of the Oxygen line pair near 765 nm measured from a laboratory breadboard across an outdoor 220m long horizontal path .

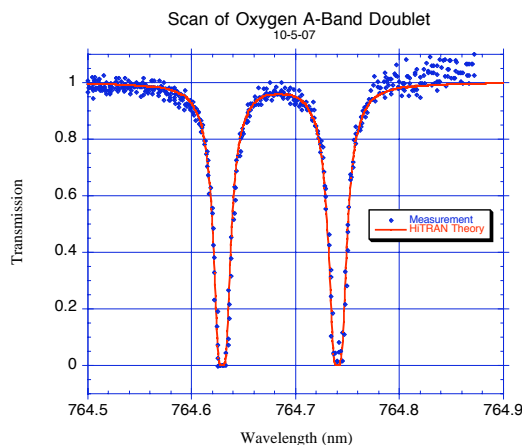


Figure 3 – Measurements of O₂ line pair using the breadboard O₂ sensor in the lab (in blue) over a 220 m horizontal path compared to the calculated O₂ line shapes from HITRAN (in red).

Figure 4 shows a 23 hour long time history of measurements of CO₂ absorption made with our breadboard sensor (in blue) across a 405 m long outdoor horizontal path. These are compared to the CO₂ concentrations in air sampled on the building rooftop measured by an in-situ sensor (Licor, in red).

Figure 5 shows a 20 hour long time series of CO₂ measurements made with our breadboard sensor when it was deployed in a van to a site in Erie CO. The measurement path was a 1.3 km long slant path, from the van to a target board near the top of the NOAA atmospheric research (BAO) tower. The sensors in the NOAA tower sampled CO₂ concentrations in air at 3 different heights, and their readings were used to predict the average concentration (in blue) in the measurement path from the instrument van to the side of the tower.

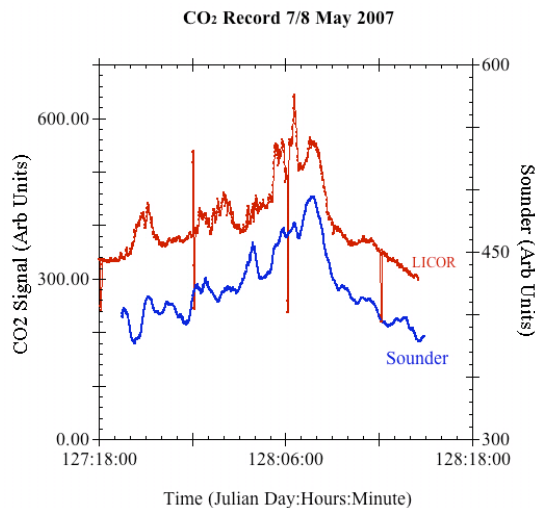


Figure 4 – Measured series of CO₂ absorption from with breadboard sensor from our lab over 405 m horizontal path over 24 hr time span in May 2007, compared to end-point CO₂ measurements made at top of our laboratory building with an in-situ sensor (LICOR).

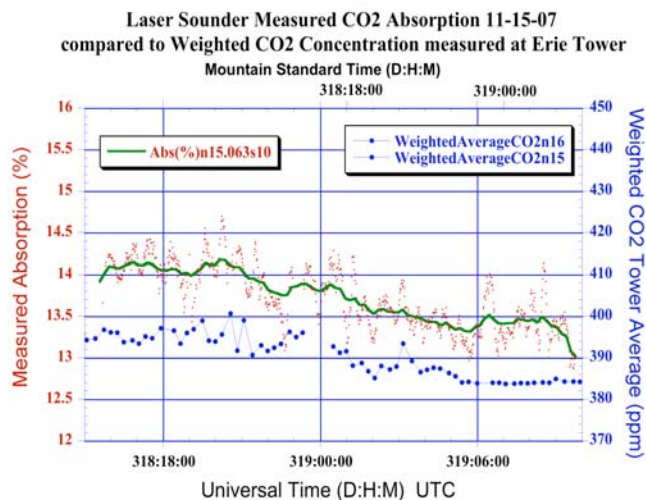


Figure 5 – Preliminary analysis of CO₂ absorption measurements made using our breadboard sensor in van over 1.3 km slant path to side of the NOAA CO₂ tower in Erie CO, compared to estimate from in-situ readings (blue) from tower. Measurement date was 11-15-07.

The green line shows the average optical absorption determined from the breadboard instrument readings during this time. These demonstration measurements show good correlations between the breadboard and the in-situ sensors.

We will describe more details of the approach and our recent measurements in the talk.

ACKNOWLEDGMENT

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